TP 5323E

A RIDE MONITOR SYSTEM FOR MAINTAINING A FLEET OF RAILWAY PASSENGER CARS

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17. Abstract

An investigation was carried out into the definition of a ride monitor system for rail passenger cars. The system continuously monitors ride characteristics in service for purposes of vehicle and track maintenance. The report defines possible alternatives, reviews respective requirements and discusses feasibility.

Investigation activities included a literature survey and an assessment of approaches taken by various railways. Documentation on some available off-the-shelf hardware was also reviewed. From these data, various alternatives for monitoring were examined and compared in terms of potential uses and requirements. A candidate system was subsequently identified and is presented.

Main conclusions are that railways take a variety of approaches, but none of the individual methods can provide the basis for an integrated system which will monitor the functional condition of both the vehicles and the track. However, current electronic hardware makes it feasible to develop a system providing continuous monitoring in every vehicle, with reporting of vehicle and track sub-standard performance. Routine data on vehicle performance in service, transferred to an off-line data base, allows establishing fleet and track averages, from which sub-standard performance can be identified and reported.

It is believed that system development should be pursued in conjunction with a passenger car fleet operator.

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17. Résumé

Ce rapport rend compte des travaux réalisés pour définir un système capable de surveiller en continu la tenue de route d'un matériel voyageurs, dans le but d'optimiser l'entretien du matériel et de la voie. Il propose diverses solutions, dont il étudie les caractéristiques, les sujétions et la faisabilité.

Les travaux ont commencé par une recherche documentaire du domaine et une évaluation de l'approche préconisée par diverses compagnies ferroviaires. Une revue a également été faite de la documentation technique concernant certains dispositifs existants. Les diverses solutions qui ont pu ainsi être dégagées ont été examinées et confrontées sur le plan des utilisations et sujétions d'emploi possibles. Enfin, un système particulier a été défini dont il est question dans le rapport.

Les conclusions de ce rapport sont que, parmi toutes les approaches possibles, aucune ne peut servir à la construction d'un système intégré capable d'assurer, simultanément, le suivi du fonctionnement du matériel roulant et celui de l'état de la voie. Néanmoins, les progrès réalisés en électronique sont maintenant tels qu'ils permettent l'étude d'un système capable de surveiller en continu chacun des véhicules séparément et de signaler tant les irrégularités de la voie que le mauvais fonctionnement du matériel. Les données recueillies en service par ce système seront transmises à un ordinateur central pour la mise à jour d'une base de données donnant les valeurs moyennes de comportement en service des matériels et de la voie. Là, il sera possible de procéder par comparaison pour dépister les comportements hors normes.

Il est préconisé que l'étude d'un tel système se poursuive de concert avec une compagnie exploitant un service de voyageurs.

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1. INTRODUCTION

The successful operation of rail passenger service depends on the achievement of a good balance between operating factors which counteract one another. Trade-offs between schedule times, train speed, safety of operation, passenger comfort, train operation costs, and fleet and track maintenance costs are required continuously.

The development of a rail vehicle ride monitoring system requires consideration of several of the operating factors indicated above. Most important, any system developed must have a demonstrable benefit and it must be straightforward to implement. The technology to implement such a system has been available for some time. However, the conceptual design of a feasible system has not previously been defined.

The overall objective motivating this research is to develop a system to monitor rail vehicle ride with a view to providing vehicle and track maintenance information as well as routine data on ride quality of vehicles in actual service.

The work leading to this report included efforts to review methods employed to monitor ride and assess comfort, efforts to consider what demonstrated technology could be applied in North American operations, and efforts to outline some new concepts for a practical ride monitor system.

2. THE NEED FOR A RIDE MONITOR SYSTEM

With the modernization of rail passenger services, there is an emphasis on improving the equipment performance. This has been particularly true in North America where, with only a few exceptions, the passenger trains share track primarily designed and maintained for freight operations. Improved vehicle performance has been achieved through introduction of sophisticated suspension systems and component designs which maximize passenger comfort and yield dynamic stability of the vehicle and its trucks.

In order to fully realize the potential performance of new equipment, maintenance must be carried out routinely and effectively. The monitoring of vehicle ride can provide an efficient means of detecting deterioriation of equipment performance and thereby flagging when maintenance is required. As well as detecting vehicle problems, a ride monitor system can routinely report on the detected condition of track. This can be especially important in those operations where the passenger vehicle, because of its design and speed of operation, is sensitive to track perturbations which would not affect other vehicles.

2.1 Problems due to Changes in Equipment Design

Traditional designs of rail vehicle suspensions have featured heavy components, often overdesigned for strength, and configured in an open manner which facilitated visual inspection. The function of an individual element was obvious. To a great extent, if a component appeared to be physically intact and in its place, one could be sure that it would function. Steel coil springs, swing hangers, friction snubbing devices, equalizer bars, and side bearings are typical of the components for which visual inspection is sufficient to allow diagnosis of potential problems. Even clearances between components can be easily gauged and shown to be within tolerance.

Total vehicle weight has been decreased to save operating costs as well as manufacturing cost. As well, steps have been taken to reduce the weight of suspension elements. Compact components having more than one function have been introduced. For example, an elastomeric chevron element can provide guidance, springing, and damping simultaneously. Hydraulic dampers, air springs, and powered linkage systems have been introduced to provide improved performance. However, the operational status of these cannot be confirmed through visual inspection alone. If complex and expensive shop testing procedures are to be avoided, observation of a vehicle's functioning while in service is required.

Ride comfort is not the only consideration. Safety of train operation depends on the proper performance of each component in the vehicle's guidance and suspension assemblies. Monitoring of performance also means monitoring of safety. Early detection

of deteriorating performance can result in changeout of faulty components before safety is compromised.

There is no argument about the superior performance possible with the newer equipment designs. As a result of extensive testing, which is now commonplace, the designs have been shown to be safe and comfortable. How sensitive this level of performance is to changes in the condition of equipment components is, however, not well known. This can only be evaluated from observation of performance in service.

2.2 Problems due to Changes in the Engineering and Maintenance Forces

A few decades ago labour-intensive procedures were of little concern. Both track and vehicles were subject to visual inspection on a frequent basis. Discrimination between vehicle and track problems was routinely made by experienced personnel. Track engineers often rode over their territory in passenger cars to monitor track condition. Today there is more reliance on instrumented track test cars which measure and report on the condition of track. One of the problems this presents is that the influence of track perturbations on the passenger vehicle is no longer directly monitored, even subjectively.

Passenger train operating crews and even passengers still play a role in monitoring conditions to the extent that reports may be generated on occasional abnormal vehicle behaviour. However, it is not clear how this relatively unstructured reporting can have any influence on car maintenance work which might follow.

These comments are primarily intended to focus discussion on the problems posed by reliance on labour-intensive and informal reporting procedures. While the benefits of applying ride monitoring equipment emerge, one must keep in mind that this will not be practical if it involves more rather than less manpower. The complete cycle of information transfer must be considered from the point of monitoring vehicle response through to the point where decisions and policies governing maintenance of equipment are made. A ride monitoring system that routinely requires skilled technicians to journey with a train for generation of vehicle ride data will never be accepted in North America. A system that involves preparation of new or more extensive written reports will not be accepted. Finally, it is the authors' opinion that individual subjective evaluation of vehicle ride data should not provide the basis for decision making.

In conclusion, a systematic and virtually automatic ride monitoring system, which objectively and reliably reports on equipment malfunction, seems to be the only practical way to proceed. While man would control the system and utilize the information it generates, he would not be a functional element of the system.

3. TRADITIONAL APPROACHES AND TECHNIQUES

As part of the study, a literature search was undertaken to review the topic. The sections below present a summary of the results of the search, and concern traditional as well as more recently developed techniques to control maintenance. Appendix A contains more detailed discussion of many of the results of the literature search.

3.1 Methods of Evaluating Vehicle Performance

Except for routine scheduled inspections, the traditional method for evaluation of vehicle performance in service is provided by subjective reporting. Although normally provided by railway personnel experienced at riding coaches, passengers also provide this kind of service through specific complaints to train personnel.

Concerning the evaluation of vehicle design configurations, instrumented tests of sample cars are usually undetaken to establish nominal vehicle performance. In itself, however, this technique does not provide information concerning variability between individual vehicles, nor does it provide information directly related to subsequent maintenance requirements.

Another approach is the use of ride meters. Ride meters are portable, self-contained instrumentation packages, which normally include two accelerometers and analog data processing equipment. Two skilled operators usually accompany the equipment to collect the data and identify it with respect to track location (watching mile boards) and other relevant information. One author (8) reports a ride meter system which has been automated in the sense that the equipment is put onto a vehicle at the start of a journey and picked up by others at completion. This system records a speed profile on chart paper and pen marks corresponding to exceedances of pre-selected thresholds of acceleration values. Location on track is inferred from the speed profile graph. From the technical references, it appears that although the ride meter technique can provide information usable for either vehicle or track maintenance, its role is mainly complementary to conventional maintenance approaches; it is certainly inadequate as a routine monitor of fleet performance.

3.2 Methods of Evaluating Track Condition

Leaving aside scheduled track maintenance programs, monitoring of track quality is performed through visual inspection by track maintenance personnel. Train crews also play a role in identifying and reporting abnormal track conditions.

The other source for such "exception" reporting has traditionally been provided by a track maintenance officer periodically riding a train over his section to identify critical locations. However, this has now mostly disappeared.

Track geometry cars are becoming more extensively used in North America. These cars are well suited to provide a graphical representation of the track geometry irregularities. They can also provide statistical parameters of the data and can be used to detect abnormal defects.

However, measuring the track geometry does not imply measuring the ride. In an effort to bridge this gap, it has been suggested to take ride measurements of the track geometry car in operation. However, this does not solve the problem caused by variability between the cars either caused by differences in design or maintenance.

3.3 Literature Survey Conclusions

To summarize, none of the individual approaches or techniques identified can provide a basis for an integrated system which will monitor the functional condition of both vehicles and track. However, the existence of such a spectrum of different approaches seems a clear indication, both of the need for ride monitoring, and of the unavailability, to date, of a technically and economically feasible solution.

4. NEW GENERAL CONCEPTS FOR RIDE MONITORING

4.1 Introduction

The purpose of this section is to present the main conceptual features of a Ride Monitor System. The concepts are novel for this application. For clarity, the technical considerations on a sample implementation are deferred to section 5.

The description of the conceptual features is intended to allow an appreciation of how such a system would operate on-line, both with respect to monitoring of ride, as well as monitoring of track and possible abnormal deterioration in service.

It also allows an appreciation of how the system could be integrated within present vehicle and track maintenance strategies, both for short and medium term objectives. Finally it allows the reader to assess the potential of the system toward longer term aspects such as planning, and in the development of new methods or equipment.

4.2 Continuous Monitoring with Exception Reports

4.2.1 On-board elements:

The system requires all cars to be equipped with permanent equipment as follows:

- a speed sensor,
- a means for location detection,
- vibration sensors,
- a local processor unit, complete with memory and programs to assess, on-line, the dynamic performance characteristics of the vehicle
- a local control panel and display unit,
- a means of transferring data from the local processor to an off-line centralized data base.

4.2.2 Real Time Monitoring Functions:

The processor unit monitors continuously the functional performance of the vehicle-track system, in terms of ride comfort, loadings on the track (from inertial reaction measurements), and possible sudden deteriorations or mal-functions (from observations of shock conditions).

Some functional aspects of the track are also continuously monitored. In this case, however, the type of track performance measured is different from that performed by track geometry cars. The criteria for track evaluation relate not to track geometry directly but rather to the response of the particular vehicle to the track at the particular speed of operation (for example the presence of long wavelength geometry defects, significant at higher speeds due to the softer suspension).

A number of performance aspects are also monitored, relating to the functional integrity of the vehicle suspension system. These correspond to well-known features inherent in the equipment hardware configuration (e.g. vehicle body resonances or wheel vibrations).

In summary, the system monitors continuously a variety of aspects covering ride performance, safety, and key functional integrity parameters relating to both the track and the vehicle.

4.2.3 Exception Reports

All measured data need not be retained. Provided the processor is supplied with decision rules or criteria related to the levels of performance acceptability, it is possible to retain only the information that is pertinent. Different ratings of performance are possible for each of the parameters being monitored.

For example:

i) The performance is within normal service levels, and the data is rejected.

ii) The performance is not within normal level, but remains within pre-determined service limits. In this case an option exists for local storage of results until the next scheduled inspection.

iii) The performance is not within service limits but remains within acceptability limits for safety or consideration of load cycles on equipment and track. An option exists for initiating an unscheduled inspection.

iv) The performance does not meet acceptable limits. An option exists to immediately alert the train crew.

"Exception reports" can be logged in the processor any time performance is not within normal performance limits. This is an essential aspect of the system.

Although there are presently no official standards for rating in-service performance, various means are available to develop them. For example, controlled tests could be performed on vehicles known to be in 'good working condition'. There is, however, an important concept to be highlighted. The system itself offers means of empirically tuning the acceptability rating through service experience (i.e. statistics on the exception reports). This is a key aspect for maintenance purposes; it allows the user to adjust the volume of data to the most effective level.

4.3 On-Line Diagnostis

The availability of specific parameters relating to the track, the vehicle and the operational conditions provide a means to diagnose causes of poor performance.

Generally, degradation of service performance (i.e. with respect to a nominal good working condition) can occur from a large variety of factors. Specific reasons for degradation often become evident only after long service and maintenance experience. This results from the fact that causes are not restricted to vehicle maintenance aspects; the track, the operational parameters, and many other factors such as seasonal effects can play important roles. For example, test results on vehicle ride have often shown large performance differences between apparently identical vehicles. In cases, simple explanations were found after tests under a variety of conditions.

The problem is therefore to identify, with reliability, the particular factors involved. This requires instrumented field test data interpreted through known physical data about the hardware.

The generation and availability of several independent performance parameters will help to diagnose causes for poor performance.

Another potential use of the track and vehicle performance indices is the possibility of generating 'exception reports' at an early stage, that is before component degradation produces objectionable operational performance (e.g. to recognize a wheel tread damage problem before it becomes objectionable from the point of view of ride or noise).

4.4 Potential as a Routine Fleet Maintenance Tool

The availability of routine data on in-service performance opens up new possibilities for more effective equipment maintenance. A major contributing factor is that the reports are produced from systematic, objective and consistent evaluation methods and avoid the variability present in subjective evaluations. Also, the reports are reliable with respect to car identification, date, time, etc.

It becomes possible to observe mean performance and typical variability amongst the vehicles of the fleet. It also becomes possible to assess performance with respect to the various routes or track sections.

The approach also allows one to observe trends with time, car mileage, or season. It becomes possible to identify cars that are worse or better than average and to measure effectiveness of specific component maintenance or changes. Means also become available for more effective trouble shooting and also to consider preventive maintenance strategies from an informed viewpoint.

4.5 Potential as a Management Tool to Assess Trade-Offs

From the point of view of safety, ride, and maintenance costs of both the vehicles and the track, successful operation of a passenger service requires concerted efforts from a variety of specialized activities. These include the design of vehicles, the establishment of track standards, the definition of operating speed policies, and above all, the maintenance of all design and operational parameters within a desired range.

From a management perspective, however, all these factors need to be weighed against each other towards a cost effective compromise. An aspect that is clear from the literature survey is that in the past it has never been practically possible to assess objectively the respective roles played by the main parameters of the overall system. Classic questions still exist regarding the relative importance of good track versus good suspensions, or the influence of operating speed on maintenance costs or safety. Many more such questions arise when considering specific design features of the vehicle or the track.

Such questions of trade-offs cannot be addressed by theoretical considerations only. Controlled testing methods are expensive, and not practical when dealing with a large number of possible combinations of conditions representing degraded component performance.

Availability of reliable data on in-service performance, combined with known physical data on the sub systems will supply data to resolve many such questions of trade-offs. The performance data enables the establishment of general bench marks; it then becomes possible to correlate variations in service performance with the known physical data about the components.

For example, when considering an actual service, all parameters are somewhat variable within the limits of the particular application. It is therefore possible to examine the influence of specific factors. Some of these may be:

- the class of car
- the type of track construction
- the known maintenance characteristics of the equipment
- the operating speed
- the effect of any change intentionally applied to the system

Essentially, it allows the user to identify the most sensitive factors in his particular operation, to assess these factors in terms of possible design or maintenance changes and related costs, and then to be able to decide on appropriate strategies with confidence.

5. A CANDIDATE RIDE MONITOR SYSTEM

5.1 Introduction

Until recently, the implementation of ride monitoring on every car would have simply been too expensive. However, the present situation, and the continued trends in electronic hardware performance (i.e. costs, power and reliability) render it practical.

In order to help others make assessments of capabilities and potential uses, as well as to help define how such a system could be integrated within actual existing maintenance and planning methods, a candidate system is described below.

Because of the inherent flexibility of the software, the system has obvious potential for adaptation to quite specific requirements of the vehicles or the track, and perhaps even to other uses. However, for the purpose of this discussion, it is restricted to ride characteristic aspects of a typical railway passenger car.

For simplicity at this stage, two aspects are not addressed in detail. Location detection, for example, does not present feasibility problems, being standard equipment on most urban rail transit systems and an area of current development in railway transportation for purposes of traffic control. The ride monitor, however, would not have the stringent accuracy and reliability requirements necessary for traffic control. The availability of check points every 15 kilometers or so ought to be sufficient. Another aspect not warranting detailed consideration at this stage is the off-line data base management system. This report only discusses the types of data and the typical processes that would be required.

5.2 On-Board Equipment

A complete system is used on each vehicle to be equipped and includes the following:

- Four vibration sensors, one lateral and one vertical at each end of the car, positioned from practical considerations of convenience and space availability.

- An axle pick-up for speed

- An external event sensor (for location detection purposes).

- A local processor unit, with memory and programs.

- A local control panel with message lights and with an output port for dumping data to a portable data collection unit.

All elements are shown schematically in figure 1. Functional elements of the local processor unit are shown in figure 2. From an operator's point of view, the data communication functions are displayed in figure 3.

5.3 On-Line Processes

The performance indices listed below have been selected arbitrarily based on a knowledge of common problem areas, as well as from items found in the literature to be of general interest. For clarity, the items are listed without detailed discussion of the implementation methods. Technical considerations on data processes are presented in appendix B.

5.3.1 Operational Performance Indices

The candidate system continuously monitors parameters related to ride, safety, and track forces. Evaluation is performed in real using the following performance indices.

- a ride comfort index, based on a frequency-weighted function selectable by the user (a modified ISO standard could be a default option, for example; see also Appendix A),

- a 'peak acceleration' index, for evaluation of transient abnormal shocks,

- a 'lateral track force' index, which corresponds to a modified version of an existing method to measure lateral wheel forces using vehicle mounted accelerometers.

5.3.2 Track Performance Indices

The candidate system evaluates two indices of track functional integrity:

- a 'rail joint' index corresponding to the presence of common staggered 39 ft. track construction.

- a 'long wavelength' index, corresponding to track geometry defect having long wavelengths affecting the vehicle at high speeds.

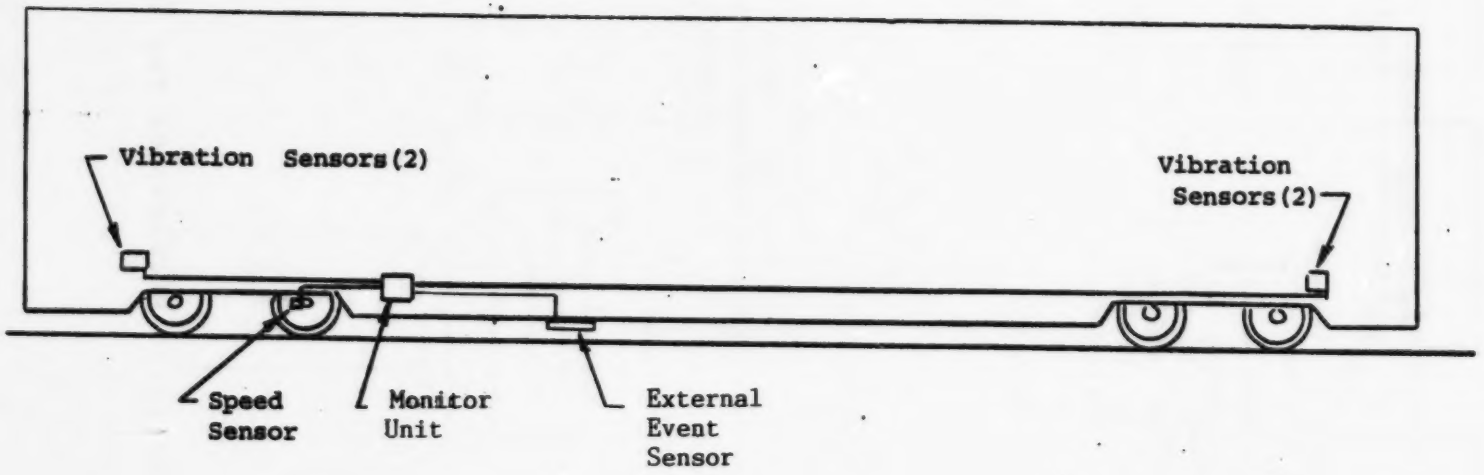

FIGURE 1 - SCHEMATIC OF HARDWARE ELEMENTS

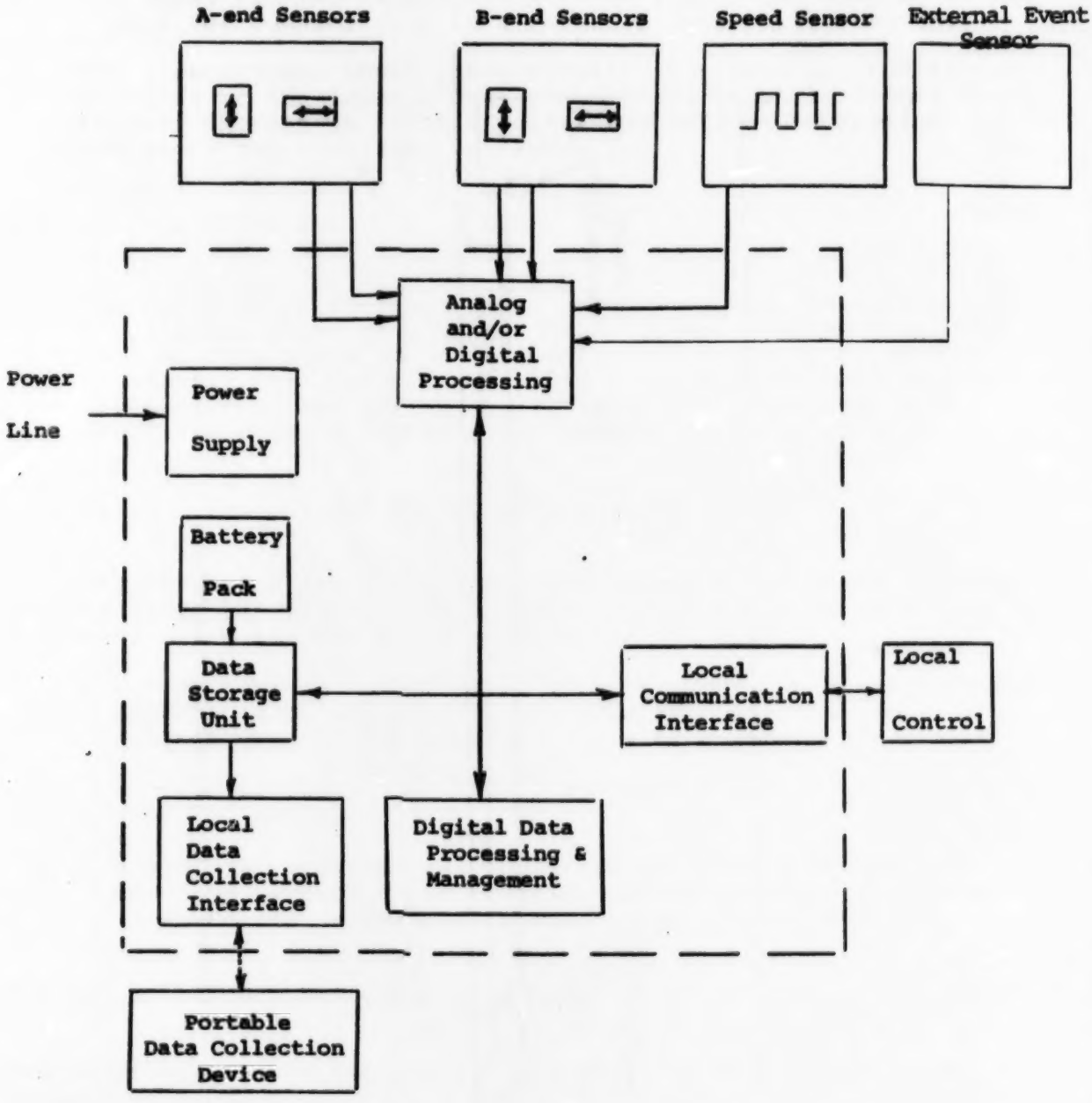

FIGURE 2 - FUNCTIONAL ELEMENTS OF THE MONITOR UNIT

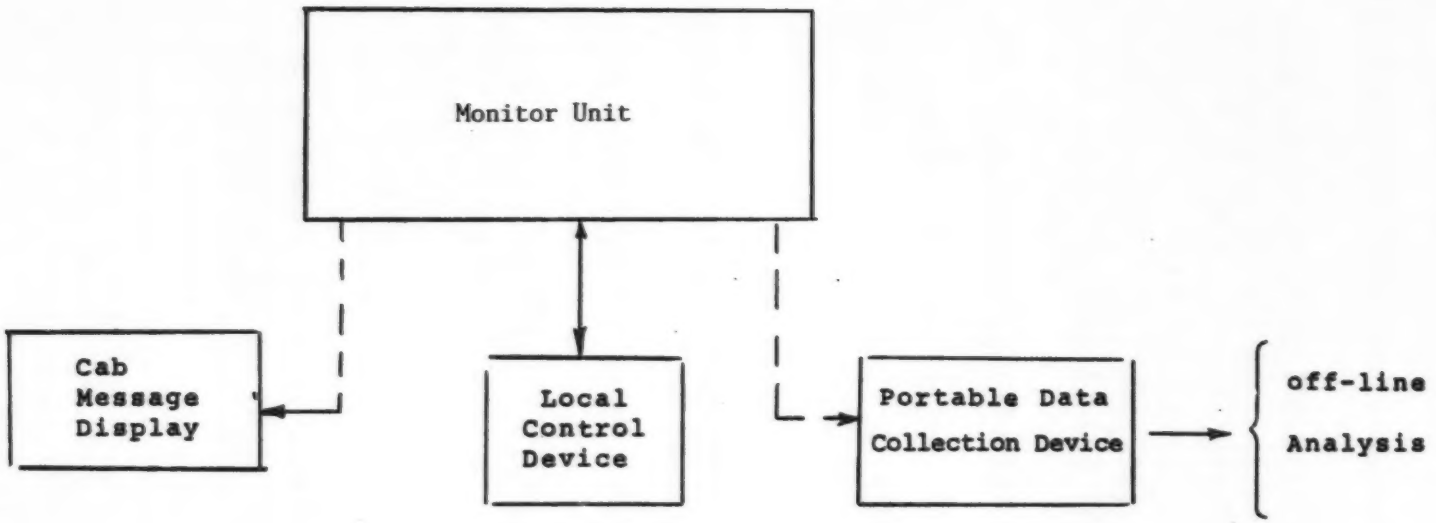

FIGURE 3 - SCHEMATIC COMMUNICATION FUNCTIONS

5.3.3 Vehicle Performance Indices

Using data processing techniques that allow discrimination between the various frequencies, it is possible to evaluate many functional performance aspects of the vehicles in terms of various mode shapes. These are not necessarily performed in real time, since some may require specific 'operating speed windows' (e.g. evaluating under-damped vertical responses only at high speeds). However, although not continuously computed in real time, there is always at least one value stored in memory, corresponding to the last result obtained.

The candidate system computes vehicle performance indices as follows:

- a 'wheel vibration' index, corresponding to flats or shells
- a 'vertical damping' index, corresponding to underdamped body vibrations in bounce or pitch,
- a 'lateral damping' index, corresponding to underdamped body lateral or, more common, yaw vibrations,
- a 'truck damping' index, corresponding to underdamped truck vibrations (commonly observed in pitch),
- a 'lateral truck stability' index corresponding to truck lateral instability oscillations,
- a 'body flexure' index, corresponding to vibrations of the car body structure (often triggered by wheel vibrations or truck pitch vibrations).

5.4 Exception Reports

Exception reports are generated and logged in memory every time one or more performance indices exceed predetermined acceptability levels. Two main levels are considered:

- 'Exception Report' Level:
  In this case, the index is within service limits but is judged unusually high. The event is kept in local memory for retrieval at the next scheduled inspection. No external messages are generated.
- 'External Message' Level:
  In this case, the index is judged to be unacceptably high. The event is logged in memory (same as for the exception report) and a message is displayed locally. Two options exist in this case. The first option is to display a message on the local control panel only, indicating, for example, that data should be transferred to the central data base for analysis. The second option is to immediately warn the train crew. This option requires a data communication link through the train.

5.5 Data Transfer Equipment

For transferring data to the centralized data base, portable data collection devices are used which can be plugged into the local processor for data retrieval. At normal scheduled inspections, where strings of cars are available, the procedure is straightforward. At other instances, for example as a result of a bad order, the data collection device can still be used. In this case, the device is also configured to be able to transfer data through telephone lines.

5.6 Off-Line Data Base and Processes

The data base exception reports are configured to be in a standard data format including car identification, time, and the various parameters of the exception reports, as described above. The data base is made from the exception reports.

The data base also contains reference or 'Bench mark' data obtained from statistics on past exception reports. These statistics are updated on a periodic basis. These basic statistics express the characteristics of whole fleets of cars, for example the overall number of exception reports on a monthly or yearly basis. Data is also available on the relative importance of the various causes of exception reports. Individual car averages are available. Data on track is also available. In a similar manner as for the fleet average, the number of occurences of exception reports are available on a route basis.

Finally, for diagnostic purposes, statistics are available concerning mean values of the various vehicle performance indices. Also available are data obtained from controlled tests on sample cars in known good working order.

From the exception report data base, and the system statistics, standard application programs can examine variability or trends. For example:

- identification of poorer cars
- identification of poorer track sections
- effects of important maintenance programs
- trends resulting from regular maintenance of components
- trends with respect to variations in operating speed
- comparison with controlled tests on vehicle having known characteristics

Many other possibilities exist at the user's convenience, considering the normally available data kept by operators on the design and maintenance features of the equipment.

6. CONCLUSIONS

The objective of the study was to define alternatives for a Ride Monitor System which provides vehicle and track maintenance information and routine data on ride quality in actual service. A literature study showed that railways currently take a variety of approaches, but none of the individual methods can provide the basis for an integrated system which will monitor the functional condition of both the vehicles and the track. However, results indicate that it is now technically feasible and practicable to individually monitor the ride of every coach as part of an integrated maintenance system. Routine data on vehicle performance in service, transferred to an off-line data base, allows establishing fleet and track averages, from which sub-standard performance can be identified and reported.

It is believed that system development should be pursued in conjunction with a passenger car fleet operator. As a first phase, functional requirements should be established for a system applied to a particular car fleet. This should be developed from considerations of actual maintenance problems and practices, acquisition of field test data and experience in the development of diagnostic algorithms.

APPENDICES

A. LITERATURE SEARCH RESULTS - EQUIPMENT MAINTENANCE AND PASSENGER COMFORT

B. TECHNICAL ASSESSMENTS AND DISCUSSIONS

C. BIBLIOGRAPHY

APPENDIX A

LITERATURE SEARCH RESULTS - EQUIPMENT MAINTENANCE AND PASSENGER COMFORT

A survey of the literature yielded approximately 150 publications relating to passenger comfort and maintenance of vehicles and track. Summaries of these were reviewed and subsequently 30 complete papers were obtained for detailed study. These are referenced in this appendix, and are listed in the Bibliography (Appendix C).

A.1 VEHICLE AND TRACK MAINTENANCE

The literature survey did not reveal a system which routinely generates data in service for the purpose of both vehicle and track maintenance. Many techniques were found, but it appears that each technique is aimed at specialized tasks.

For example, on high speed passenger lines in Japan and in Europe, there is a close monitoring of track geometry using a dedicated vehicle, with test crews specialized in the interpretation of measured data (5, 6, 7, 8)*. The test crew has the responsibility for detecting and reporting changes in track condition from the previous run. They in turn alert track maintenance personnel to schedule inspection of locations where track irregularities may present either a safety problem or an undesired input to the passenger vehicles.

In one case (8), the dedicated track geometry car is equipped with ride measuring equipment to measure coach ride at the same time the track geometry is recorded. The coach ride data is used to estimate passenger comfort on the remaining fleet. This approach assumes that passenger vehicle characteristics are similar to those of the track geometry car.

Various references (3, 11, 30, 31) report the use of portable ride meters, where technicians ride a revenue coach with vibration sensors, chart recorders, and perform on-line evaluation of a comfort index on an adjustable time or distance basis. Location on track and speed evaluation are usually determined by watching milepost markers; technicians running the equipment attempt to diagnose conditions causing undesired vehicle response.

In one case, the Tokyo-Okayama line, a portable automatic vibration measuring system is used (8). In operation, the system is installed on the last coach of the train at the beginning of a run and removed at the completion of the trip. The system automatically records on chart paper the speed profile (drawn on a distance basis) and the output of two markers indicating occurrences of critical high values of lateral and vertical acceleration. Locations where the critical values are encountered are identified from the chart paper, and this information is passed to the train control centre (for track inspection or speed reduction, as required). This system can only be used on cars that have been built to accomodate it (since 1971). No details are given on the hardware configuration of this system.

One reference was found (7) in which it is reported that permanent wiring is installed on the cars to facilitate installation of vibration sensors and analog data recording equipment. It is not precisely stated how the system is used and how frequent such inspections are done, but the system is not automatic with respect to speed or location detection (it relies on the use of push buttons to identify mileposts) and relies on off-line data analysis (FM tape recorders are used to collect data).

* Numbers in brackets refer to references in appendix C.

A.2 PASSENGER COMFORT

Extensive reference material exists relating to the evaluation of passenger comfort. An overview on general aspects of comfort is given in reference (9); a review of field and laboratory studies on human reaction to vibration is presented in reference (10).

Generally, there is no consensus of opinion on specific criteria to evaluate human comfort. Experimental data show differences which may be attributable in part to the difficulty of defining an objective qualifier (e.g. "fairly comfortable"). Several different techniques have been used by various railway administrations (20), such as Sperling, Mauzin, and Janeway, to list a few. Most railways have considered use of the recent ISO 2631 Standard (24) which is primarily aimed at defining acceptable human exposure to whole body vibrations, but which contains guidelines for the evaluation of comfort ("reduced comfort boundaries"). Although the ORE has pointed out some limitations and difficulties in the rigorous application of the Standard (see discussion in Appendix B), it appears that specific recommendations are available to resolve the problem (25).

In summary, however, it appears that this subject should not be a critically sensitive aspect of a system whose primary objective is to provide an improvement in ride comfort through facilitating improved maintenance of vehicle and track.

APPENDIX B

TECHNICAL ASSESSMENTS AND DISCUSSIONS

This section provides technical information concerning the various on-car subsystems and on-car data processing. Technical requirements and possible alternatives are outlined. Questions of technical feasibility are also discussed.

B.1 SENSORS

Vibration Sensor

Traditionally, vertical and lateral accelerations at one location have been used in rail vehicles to evaluate comfort. To monitor the response characteristics of the vehicle body, it is necessary to have two pairs of sensors per vehicle, a lateral and a vertical at each end. Sensor characteristics may be based on ISO Standard 2634 (24)* requiring response from 1 to 80 Hz. Methods for outlining sensor specifications are defined in ISO specification 184 (26) which lists all aspects that should be considered.

Speed Sensor

A common type of speed sensor found on rail vehicles consists of a magnetic probe and a toothed disk on the axle. Such speed sensors are used on many recently built passenger cars for wheel-slip protection. These common devices, however, are not configured to give direction of motion, and the output signal is poor at low speed. Therefore, they would not be adequate for location detection. However, this is not seen as a technical feasibility problem since a variety of off-the-shelf devices are available which can meet the requirements.

For location identification between check points, axle pick-ups (i.e. countins of wheel revolutions) appears adequate.
Although wheel creepage (i.e. partial wheel slip) does occur, this should not introduce intolerable errors. Effects of wheel wear may necessitate adjustment but it is possible to accomplish this on-line from data on station locations.

* Numbers in brackets refer to references in appendix C.

B.2 DATA PROCESSES

This section describes requirements for comfort evaluation and computation of the various performance indices discussed in the report.

Passenger Comfort

General considerations on comfort evaluation have been given in Appendix A. Considerations on data processes are given below.

Most experimental and laboratory results on comfort evaluation relate to situations where the severity or characteristic of the vibration is constant (e.g. sinusoidal or stationary random).

Methods used in the past to assess ride can be classified into two. One is based on counting instances of acceleration above specified levels. Although simple to implement, it is difficult to interpret in terms of subjective evaluation. The second approach is based on the hypothesis that human sensitivity follows a unique frequency dependent relationship.

When dealing with random signals, this technique is directly implementable using electronics. This implementation is also permissible by ISO Standard (24).

Given a frequency dependent relationship, the vibration signal must be transformed into a comfort qualifier, and various systems have been used in the past. The ISO recommends use of r.m.s. value for signal averaging; this value is then transformed into an 'allowable time exposure' representing a limiting time for meeting a certain comfort boundary. All these processes are straightforward. Some difficulties remain, however, in the strict application of the ISO standard; for example:

i) Valid for 'whole-body vibrations' only; considering that most passengers are seated, measurements would need to be compensated to, or measured at, the seat.

ii) Valid for frequencies between 1 and 80 Hz only; an important portion of the signal is in the 0-1 Hz range.

iii) Valid for 'crest factors' less than 3: The crest factor, the ratio of peak to r.m.s. acceleration values, is generally above three on rail vehicles when considering complete journeys.

However, the ORE has considered these difficulties and recommendations for specific solutions are available (25).

Operational Performance Indices

Example indices given in the candidate system are:

- 'Ride comfort'
- 'Peak acceleration'
- 'Lateral Track Force'

Computation of a ride index would be straightforward considering the previous discussion on comfort. The selection of appropriate levels and time constants can be determined at the development stage. Such decisions can be made either empirically from examination of typical comfort levels or from desired performance specifications.

Comparison with predetermined acceleration levels would also be straightforward. Again the selection of the appropriate threshold levels can be made at the development stage based on statistical analysis of vibrations in service. Although peak acceleration monitoring would be primarily aimed at detecting abnormal conditions, it has been shown in one case (4) that empirical relationships could be found between peak lateral accelerations and peak lateral wheel-rail forces. In this sense, the monitoring of peak acceleration can be viewed as a possible means of identifying excessive loads on the track.

The 'lateral track force' index refers to the force applied by the car body on the track through the complete truck assembly. The approach is a variation of a known method to measure dynamic lateral wheel forces on the track from the truck (for example, such a method has been used on the LRC locomotive prototype and results for peak values compared reasonably well with those obtained from instrumentation of the primary suspension). In the case of the candidate ride monitor system however, only the force component from the car at the truck is evaluated. The technique is straightforward to implement, provided data is available on the inertial characteristics of the vehicle body. A specific requirement of this technique is that a pair of accelerometers (one at each end) must be used, to derive the acceleration level present at the 'percussion point' of the vehicle body. It is realized that inertial characteristics vary depending on the passenger load, but in the ride monitor application the objective is mainly to identify exceptional cases that need further attention; therefore, a certain degree of error appears tolerable.

Track Performance Indices

As previously mentioned, the objective in this application is not to measure the track geometry. It is rather to evaluate the presence of combined conditions of track geometry and vehicle characteristics that together influence ride qualities significantly.
The process consists of evaluating the strength of the ride signal in narrow frequency bands corresponding to the selected track input wavelength at the given operating speed. For applications to North American services, a 39 ft. base wavelength could be selected. Another functional aspect of the track is the presence of longer

(periodic or transient) wavelengths, exciting the vehicle at or below its main natural frequencies.

Vehicle Performance Indices

The computation of vehicle performance indices relies on discrimination between the various frequencies present in the vibration signal at a given speed. As previously listed, the vehicle performance indices were labeled as follows in section 5.

- 'Wheel Vibration'
- 'Vertical damping'
- 'Lateral damping'
- 'Truck damping'
- 'Lateral Truck Stability'
- 'Body Flexure'

Each of the above phenomena has specific characteristics in the frequency domain. The evaluation of the presence of the various frequency components can be performed using Fourier analysis techniques. For example, the evaluation of wheel revolution related vibrations would be straightforward.

It also appears feasible to detect wheel tread surface defects such as shelled tread and built-up treads. This condition is generally noticeable at low speeds (i.e. 5-10 mph) and gives continuous general harshness to the ride which is normally smooth.

The evaluation of damper condition is feasible considering that at higher speeds (i.e. high end of the normal passenger train operating speeds) the common periodic track irregularities consisting of rail joints and harmonics are above the natural frequencies of the vehicle main suspension. At these speeds, the system can be treated as being excited by a random signal. Autocorrelation techniques applied to the various car body mode signals should indicate the characteristics of the vibration decay. These are straightforward mathematical processes. The reliability and accuracy of such a technique would be best when damping is small; that is, when the damper condition is poor and requires attention.

Lateral truck instability usually has a specific characteristic in terms of frequency and operating speed. Although the most violent oscillations are found on the trucks, the vehicle has a response which is measurable. Amplitude and frequency characteristics depend on the truck design and test data would be required in order to tune the computational procedures.

B.3 GENERAL CONSIDERATIONS ON HARDWARE

It is premature at this time to enter into evaluation of specific hardware components, especially considering the rapid evolution of available products. However, some effort was spent in reviewing the functional capabilities of various existing components. The following general conclusions were arrived at.

Present LSI circuits have the capability of performing all the tasks described for the system. Numerical computations can be significantly speeded up by using special function devices such as arithmetic processors, signal processors, and various other devices such as signal converters or programmable interfaces. Use of such specialized devices can provide numerical processing power comparable to minicomputer systems.

Current solid state memory technology is capable of meeting the system requirements. For example, single chips would be capable of storing indices for several hundred kilometers at intervals of one quarter kilometer.

Although system development should be achieved using off-the-shelf general purpose systems, production units could be produced from components at significantly lower cost.

B.4 CONSIDERATIONS ON RELIABILITY

High reliability must be obtained under typical railway operating conditions. These include possible power failures, occasional storage for long periods at temperatures possibly varying between -40 degrees and 65 degrees C, as well as shocks and vibrations. However, these conditions are not exceptional compared to some present uses of micro-electronics in industrial and military applications.

An aspect worth mentioning is that the use of computers offers an advantage with respect to system testing, including sensors. Most commercial vibration sensors offer means to perform electrical tests. They can also be checked using gravity. In addition, problems related to sensor mechanical parts are often traceable by examination of the signal output (e.g. ringing at their natural frequency), and therefore functional monitoring of sensors is possible in a manner similar to that for vehicle performance indices.

APPENDIX C

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